

# Symmetry breaking effect on determination of polarized and unpolarized parton distributions

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## Abstract

We perform a new extraction for unpolarized and polarized parton distribution functions considering a flavor decomposition for sea quarks and applying very recent deep inelastic scattering (DIS) and semi inclusive deep inelastic scattering (SIDIS) data in the fixed flavor number scheme (FFNS) framework. In the new symmetry breaking scenario the light quark and antiquark densities are extracted separately and new parametrization forms are determined for them. The heavy flavors contribution, including charm and bottom quarks, are also taken to be account for unpolarized distributions.

**Keywords:** Parton distribution functions; symmetry breaking.

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## 1. Introduction

In the recent years our knowledge about the structure of the nucleons has improved and by the increase of both acceptable accuracy and the volume of data from deep inelastic scattering processes, new investigations are also in remarkable progress [1, 2].

In DIS experiments the photon transfers the electron vertex momentum to the proton and scatters off spin- $\frac{1}{2}$ , pointlike quark component of it. The probability that the parton of flavor  $f$  carries fraction  $x$  of the struck proton momentum is called parton distribution functions (PDFs) and plays a very important role to determine DIS cross sections. The extraction of PDFs and polarized PDFs (PPDFs) is developed to very precise QCD analysis in next-to-leading order (NLO) or even next-to-next-to-leading order (NNLO) approximation which are based on new model independent hypotheses [3–15].

The inability of inclusive DIS data to distinguish quarks from antiquarks was always the main reason of symmetry consideration by many theoretical groups until very recent years and now the growing of SIDIS for polarized

and Drell-Yan experiments for unpolarized data [16–19] is the motivation of considering symmetry breaking models in the new analysis.

In our previous works we studied the impact of the recent very precise inclusive structure functions data from DIS experiments on the determination of unpolarized and polarized parton distributions in the standard scenario i.e.  $\bar{u} = \bar{d} = \bar{s}$  [20, 21], and now we apply SU(2) and SU(3) symmetry breaking scenario and have  $\bar{u} \neq \bar{d} \neq \bar{s}$  in determination of PDFs and PPDFs like what other groups have studied recently [22–25]. In the current analysis we apply experimental data of inclusive Neutral Current Deep Inelastic Scattering (NC DIS) for unpolarized and spin-dependant DIS and SIDIS data for polarized QCD fit process explained in detail in [26, 27]. The organization of the present paper is as follows: determination of unpolarized PDFs is presented in Sec. 2 and polarized PDFs extraction is discussed in Sec. 3. Finally in Sec. 4 we summarize and give the conclusion of the analysis.

## 2. Determination of unpolarized parton distributions

The total structure function of proton  $F_2^p(x, Q^2)$  in  $\overline{\text{MS}}$  factorization scheme can be written in NLO approximation as [28]

$$F_2(x, Q^2) = F_{2,\text{NS}}^+(x, Q^2) + F_{2,S}(x, Q^2)$$

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$$+ F_2^{(c,b)}(x, Q^2, m_{c,b}^2), \quad (1)$$

here the non-singlet contribution is given by

$$\begin{aligned} \frac{1}{x} F_{2,NS}^+(x, Q^2) &= \left[ C_{2,q}^{(0)} + \frac{\alpha_s}{4\pi} C_{2,q}^{(1)} \right] \\ &\otimes \left[ \frac{1}{18} q_8^+ + \frac{1}{6} q_3^+ \right] (x, Q^2), \end{aligned} \quad (2)$$

and the flavor singlet contribution is

$$\begin{aligned} \frac{1}{x} F_{2,S}(x, Q^2) &= \frac{2}{9} \left\{ \left[ C_{2,q}^{(0)} + \frac{\alpha_s}{4\pi} C_{2,q}^{(1)} \right] \otimes \Sigma \right. \\ &\quad \left. + \frac{\alpha_s}{4\pi} C_{2,g}^{(1)} \otimes g \right\} (x, Q^2). \end{aligned} \quad (3)$$

The contribution of heavy flavors  $F_2^{c,b}(x, Q^2)$  have been also added in our analysis and they are taken as in Ref. [29]. In the above equations  $\alpha_s$  is the strong coupling constant,  $C_{2,q}^{(0)}(z) = \delta(1-z)$ ,  $C_{2,q}^{(1)} = C_{2,NS}^{(1)}$  and the additional NLO  $C_{2,g}^{(1)}$  and  $C_{2,NS}^{(1)}$  are the corresponding known Wilson coefficients which can be found in Ref. [30]. The PDFs combinations of  $q_3^+$  and  $q_8^+$  and  $\Sigma(x, Q^2)$  are also well determined in the literatures [26]. Here we consider symmetry breaking for  $\bar{u} \neq \bar{d} \neq \bar{s}$  and a symmetry for strange sea,  $s = \bar{s}$ , so our analysis is effected by these new assumptions. For our QCD fit we use the following parametrization forms of the parton distribution functions at the input initial scale  $Q_0^2=2 \text{ GeV}^2$

$$\begin{aligned} xu_v &= A_{u_v} x^{\alpha_{u_v}} (1-x)^{\beta_{u_v}} (1 + \gamma_{u_v} x^{\delta_{u_v}} + \eta_{u_v} x), \\ xd_v &= A_{d_v} x^{\alpha_{d_v}} (1-x)^{\beta_{d_v}} (1 + \gamma_{d_v} x^{\delta_{d_v}} + \eta_{d_v} x), \\ x\Delta &= A_{\Delta} x^{\alpha_{\Delta}} (1-x)^{\beta_{\Delta} + \beta_{\Delta}} (1 + \gamma_{\Delta} x^{\delta_{\Delta}} + \eta_{\Delta} x), \\ xS &= A_S x^{\alpha_S} (1-x)^{\beta_S} (1 + \gamma_S x^{\delta_S} + \eta_S x), \\ xg &= A_g x^{\alpha_g} (1-x)^{\beta_g} (1 + \gamma_g x^{\delta_g} + \eta_g x), \end{aligned} \quad (4)$$

here we take  $x\Delta = x(\bar{d} - \bar{u})$ ,  $xS = 2x(\bar{u} + \bar{d} + \bar{s})$  and as we mentioned above  $s = \bar{s}$ , since our used data sets are not sensitive to the special choice of the strange sea parton distributions. Due to applying some reasonable constraints in the parameter space of our global QCD fit [26], only 13 parameters remained free for all parton flavor in the final minimization. The  $\chi_{\text{global}}^2$  in global fit procedure minimization is defined as [28]

$$\chi_{\text{global}}^2 = \sum_{i=1}^{n^{\text{data}}} \left[ \left( \frac{N_i - 1}{\Delta N_i} \right)^2 + \sum_{j=1}^{n^{\text{data}}} \left( \frac{N_j D_j^{\text{data}} - T_j^{\text{theory}}}{N_j \Delta D_j^{\text{data}}} \right)^2 \right], \quad (5)$$

where  $n^{\text{data}}$  shows the number of included data points and  $D_i^{\text{data}}$ ,  $\Delta D_i^{\text{data}}$ , and  $T_{i,j}^{\text{theory}}$  are the value, uncertainty

and theoretical value for the  $n^{\text{th}}$  data point of the  $i^{\text{th}}$  experiment.  $\Delta N_n$  is known as the experimental normalization uncertainty and the value of  $N_n$  shows an overall normalization factor for the  $n^{\text{th}}$  experiment data. In our global fits, we get  $\frac{\chi^2}{\text{NDF}} = 1.098$  and for the total number of used data points we put  $n^{\text{data}} = 3279$  introduced in Ref. [26].

Our analysis process is accomplished using the QCD-PEGASUS package in the fixed-flavor number scheme with consideration of massless partonic flavors and  $N_f = 3$  [31]. The results of fitted parton distribution functions, known as KKT12, and their errors at the initial scale are presented in Fig. 1 and regarding to the symmetry breaking scenario, a comparison of our results for  $\bar{d} - \bar{u}$  and  $\bar{d}/\bar{u}$  as a function of  $x$ , with the results from other groups and experimental data is shown in Fig. 2 in NLO approximation.

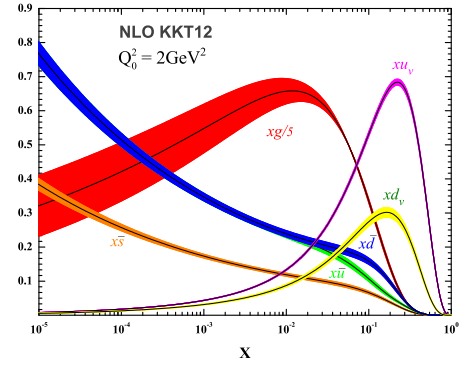


Figure 1: The KKT12 parton distribution functions as a function of  $x$  at initial scale  $Q_0^2 = 2 \text{ GeV}^2$  in NLO approximation.

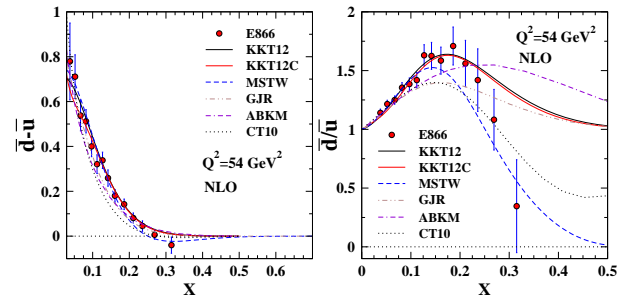


Figure 2: Our results for  $\bar{d} - \bar{u}$  and  $\bar{d}/\bar{u}$  as a function of  $x$  in comparison to the results from CT10 [4], MSTW08 [28], ABKM10 [32] and GJR08 [33]. The E866 results [16, 17], scaled to  $Q^2=54 \text{ GeV}^2$ , are also shown as circles.

### 3. Determination of polarized parton distributions

Generally we consider a nucleon is formed of massless partons that have negative and positive helicity distributions  $q_{\pm}(x, Q^2)$  and the difference

$$\delta q(x, Q^2) = q_+(x, Q^2) - q_-(x, Q^2), \quad (6)$$

shows how much the parton  $q$  is responsible for the original proton polarization and is called polarized parton distribution function.

In the present analysis for PPDFs determination we subjoin very recent SIDIS experimental data for polarized parton densities from HERMES [18] and COMPASS [19] to DIS experimental data of Ref. [20] since these additional experiments help us to apply symmetry breaking and recognize  $\bar{u}$ ,  $\bar{d}$  and  $\bar{s}$  separately.

The polarized structure function  $g_1(x, Q^2)$  is written in terms of a Mellin convolution of PPDFs with the relevant known Wilson coefficients  $\Delta C_{q,g}$  [34]

$$g_1(x, Q^2) = \frac{1}{2} \sum_{q=u,d,s} e_q^2 \left\{ \left[ 1 + \frac{\alpha_s}{2\pi} \Delta C_q \right] \otimes [\delta q + \delta \bar{q}] + \frac{\alpha_s}{2\pi} 2\Delta C_g \otimes \delta g \right\} (x, Q^2), \quad (7)$$

where  $\alpha_s$  is the strong coupling constant,  $e_q$  shows the charge of the quark flavor  $q$  and  $\{\delta q, \delta \bar{q}, \delta g\}$  are the corresponding PPDFs. For our analysis we choose following functional forms for polarized PDFs in the initial scale  $Q_0^2 = 4 \text{ GeV}^2$

$$\begin{aligned} x \delta u_v &= \mathcal{N}_{u_v} \eta_{u_v} x^{a_{u_v}} (1-x)^{b_{u_v}} (1 + d_{u_v} x), \\ x \delta d_v &= \mathcal{N}_{d_v} \eta_{d_v} x^{a_{d_v}} (1-x)^{b_{d_v}} (1 + d_{d_v} x), \\ x \delta \Delta &= \mathcal{N}_{\Delta} \eta_{\Delta} x^{a_{\Delta}} (1-x)^{b_{\Delta}} (1 + c_{\Delta} \sqrt{x}), \\ x \delta \Sigma &= \mathcal{N}_{\Sigma} \eta_{\Sigma} x^{a_{\Sigma}} (1-x)^{b_{\Sigma}} (1 + c_{\Sigma} \sqrt{x}), \\ x \delta s &= \mathcal{N}_s \eta_s x^{a_s} (1-x)^{b_s} (1 + d_s x), \\ x \delta g &= \mathcal{N}_g \eta_g x^{a_g} (1-x)^{b_g}, \end{aligned} \quad (8)$$

where  $\delta \Delta = \delta \bar{d} - \delta \bar{u}$  and  $\delta \Sigma = \delta \bar{d} + \delta \bar{u}$ . The normalization constants  $\mathcal{N}_q$  are determined such that the value of  $\eta_q$  become the first moments of PPDFs, i.e.  $\eta_q = \int_0^1 dx \delta q(x, Q_0^2)$ . Since the current SIDIS data are not sufficient yet to differ  $s$  from  $\bar{s}$ , we apply  $\delta s = \delta \bar{s}$  throughout, also we have to make some constraints on the parameter space to control the  $x$  dependance of PPDFs [27] like what we do for unpolarized PDFs.

The value of parameters  $\eta_{u_v}$  and  $\eta_{d_v}$  shows the first moments of polarized valence quark distributions  $\delta u_v$  and  $\delta d_v$  which can be linked to  $F$  and  $D$  determined in neutron and hyperon  $\beta$ -decays [35] by assuming  $SU(2)$  and  $SU(3)$  flavor symmetries [24]. These quantities result into  $\eta_{u_v} = +0.928 \pm 0.014$  and  $\eta_{d_v} = -0.342 \pm 0.018$

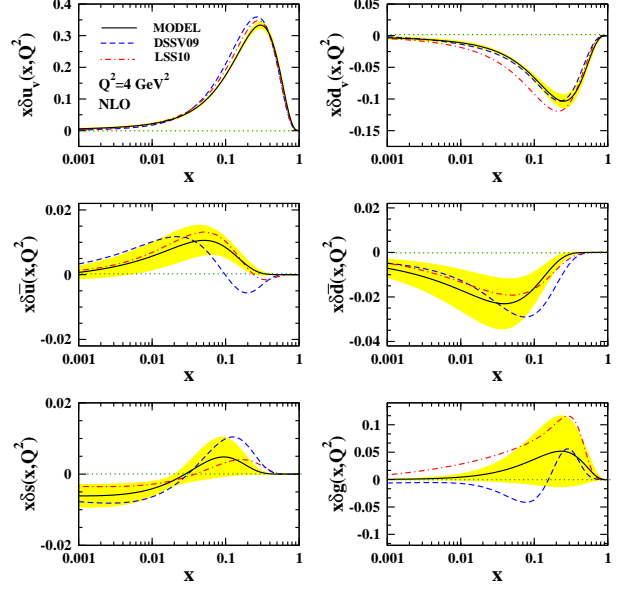


Figure 3: The quark polarized distributions as function of  $x$  comparing with DSSV09 [24] and LSS10 [25] models in NLO approximation.

as shown in Ref. [20]. Since in the present analysis we are not interested to force  $SU(2)$  and  $SU(3)$  flavor symmetry, we should relax the symmetry relations in  $\eta_{u_v, d_v}$  measurements by introducing two flexible parameters,  $\varepsilon_{SU(2)}$  and  $\varepsilon_{SU(3)}$  like what DSSV09 [24] has proposed

$$\Delta \Sigma_u - \Delta \Sigma_d = (F + D) [1 + \varepsilon_{SU(2)}], \quad (9)$$

$$\Delta \Sigma_u + \Delta \Sigma_d - 2\Delta \Sigma_s = (3F - D) [1 + \varepsilon_{SU(3)}]. \quad (10)$$

In above equations  $\varepsilon_{SU(2,3)}$  determine the deviation value from  $SU(2)$  and  $SU(3)$  symmetries and are also considered in the QCD global fit as free parameters.

Our polarized analysis is done using the QCD-PEGASUS package in the fixed-flavor number scheme with consideration of massless partonic flavors and  $N_f = 3$  same as unpolarized procedure [31]. Finally our minimization for  $\chi^2_{\text{global}}$  is performed with 15 unknown parameters from PPDFs parametrization forms and we obtain  $\frac{\chi^2}{NDF} = 0.829$  which shows an acceptable fit to the number of 491 experimental data. Fig. 3 shows the comparison of extracted PPDFs with other models and the symmetry breaking effect on  $\delta \bar{u}$  and  $\delta \bar{d}$  difference, comparing with the results from other models and experimental data, is presented in Fig. 4.

### 4. Summary and conclusions

In the present paper we present two NLO QCD analysis of the unpolarized and polarized data from DIS and

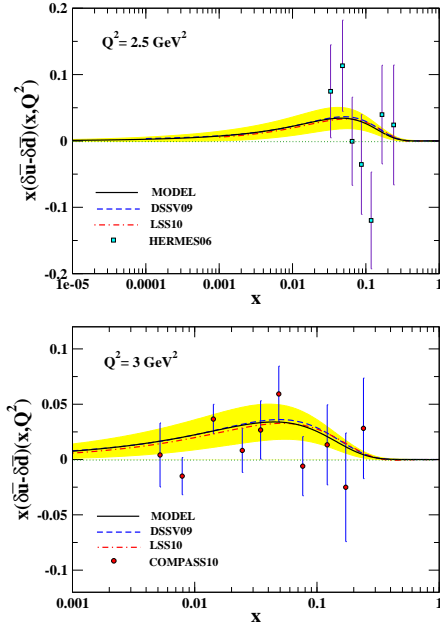


Figure 4: The quark polarized distributions for the difference of  $x(\delta\bar{u} - \delta\bar{d})$  at  $Q^2 = 2.5, 3 \text{ GeV}^2$  comparing to results from other models and experimental data [18, 24, 25].

SIDIS experiments. While the analysis we always have  $SU(2)$  and  $SU(3)$  symmetry breaking i.e.  $\bar{u} \neq \bar{d} \neq \bar{s}$ , but we consider  $s = \bar{s}$  since the current available experimental data are not yet enough to recognize them. The effect of symmetry breaking in determining PDFs and PPDFs is shown and also we find out that the gluon helicity is still not well known [27]. Having extracted PDFs and PPDFs, we can determine nucleon unpolarized and polarized structure functions  $F_2$  and  $g_1$  too. In general our results are in good accord with other models determinations and this proves the progress of the way toward a precise description of the unpolarized and polarized parton component of the nucleon.

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